Calculating the bound on the light Higgs mass in general SUSY models*

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Abstract

In the Minimal Supersymmetric Standard Model (MSSM) the existence of an upper bound on the mass of the $CP = +1$ lightest Higgs boson, equal to m_Z at tree–level and $\lesssim 120\ GeV$ after the inclusion of radiative corrections, has important phenomenological consequences for Higgs searches. A similar bound, independent of mass parameters other than the electroweak scale, can be calculated in supersymmetric models with an extended Higgs sector. In models with arbitrary Higgs sectors perturbative up to $10^{16}\ GeV$, we find, including radiative corrections, $m_h \lesssim 155\ GeV$ for $m_t \lesssim 190\ GeV$.

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Supersymmetric models have more Higgs degrees of freedom than the Standard Model but due to Supersymmetry their Higgs sectors are also more constrained [1]. In particular, the MSSM needs two Higgs doublets H_1, H_2 with opposite hypercharges and from those, two scalar, one pseudoscalar and two charged states show up in the Higgs spectrum. From the fact that quartic couplings of the Higgs bosons are given by the gauge couplings, the interesting tree–level inequality results

$$m_h \leq m_Z \mid \cos 2\beta \mid , \tag{1}$$

where m_h is the mass of the $CP = +1$ lightest Higgs scalar h^0, $\tan\beta \equiv v_2/v_1$, and $v_i \equiv \langle H_i^o \rangle$.

The phenomenological consequences of the upper bound (1) are clear: it would imply that LEP-200 should discover this Higgs [2]. However, it has been found recently that radiative corrections due to top–stop loops can change (1) sizeably. These corrections can be calculated by different methods[3] and turn out to depend on the mass of the top m_t, $\tan\beta$ and the scale of supersymmetry breaking Λ_s. This is shown in Fig. 1a where the bound on m_h includes two–loop radiative corrections as calculated in Ref. 4. For example, for $\Lambda_s \lesssim 10\ TeV$ and $m_t \lesssim 150\ GeV$ one finds $m_h \lesssim 115\ GeV$.

In a supersymmetric model with an enlarged Higgs sector, *i.e.* with extra Higgs fields apart from the two doublets H_1, H_2 of the MSSM, the bound (1) changes but still exists. It can be shown that this bound comes from the quartic couplings in the Higgs potential and in the general case these are not only gauge couplings (coming from D–terms as in the MSSM) but also Yukawa couplings that can be present in the superpotential of the model (and contribute to the potential through F–terms).

To be more specific, suppose that H_1, H_2 are the doublets that take non–zero vevs ($\langle H_i^0 \rangle = v_i^2$) and couple to quarks and leptons. The potential for their neutral components H_1^0, H_2^0 has some quartic gauge couplings identical to the MSSM ones plus some new quartic couplings from F–terms. The origin of these is clear: now the superpotential can have trilinear terms of the form $\lambda \phi H_i^0 H_j^0$ $(i, j = 1, 2)$ with ϕ some Higgs scalar. For a superpotential that includes a part like

$$f = \lambda_0 \phi_0 H_1^0 H_2^0 + \frac{1}{2}\lambda_1 \phi_1 H_1^0 H_1^0 + \frac{1}{2}\lambda_{-1}\phi_{-1} H_2^0 H_2^0 + \cdots, \tag{2}$$

the bound (1) changes to[5]

$$m_h^2/v^2 \leq \frac{1}{2}(g^2 + g'^2)\cos^2 2\beta + \lambda_0^2 \sin^2 2\beta + \lambda_1^2 \cos^4\beta + \lambda_{-1}^2 \sin^4\beta, \tag{3}$$

where $v^2 \equiv v_1^2 + v_2^2$, and $g,\ g'$ are the $SU(2) \times U(1)$ couplings. For $\lambda_k = 0$ the bound (1) is recovered.

$SU(2) \times U(1)$ invariance requires the ϕ_k's to be singlets or neutral components of $Y = 0, \pm 1$ triplets. So that, concerning this mass bound problem, the most general superpotential can be written as

$$f_h = \vec{\lambda}_1 \cdot \vec{S} H_1 {\circ} H_2 + \vec{\lambda}_2 \cdot \vec{\Sigma} H_2 {\circ} H_1 + \frac{1}{2}\vec{\chi}_1 \cdot \vec{\Psi}_1 H_1 {\circ} H_1 + \frac{1}{2}\vec{\chi}_2 \cdot \vec{\Psi}_2 H_2 {\circ} H_2 + \mathcal{O}(\Sigma^3, ...). \tag{4}$$

Here, we have gauge singlets $S^{(\sigma)}$, $\sigma = 1, ..., n_s$; $SU(2)$ triplets $\Sigma^{(a)}$, $a = 1, ..., t_o$, with $Y = 0$; and $SU(2)$ triplets $\Psi_1^{(i)}$, $\Psi_2^{(i)}$, $i = 1, ..., t_1$, with $Y = \pm 1$. This superpotential gives a tree–level bound (3) of the form[7]

$$m_h^2/v^2 \leq \frac{1}{2}(g^2 + g'^2)\cos^2 2\beta + (\vec{\lambda}_1^2 + \frac{1}{2}\vec{\lambda}_2^2)\sin^2 2\beta + \vec{\chi}_1^2 \cos^4\beta + \vec{\chi}_2^2 \sin^4\beta. \tag{5}$$

This bound is independent of supersymmetric mass terms or soft breaking parameters. The gauge part is that of the MSSM and reproduces the mass of the Z provided that no other Higgs representations contribute to it (if this is not the case this gauge contribution is smaller and the bound stronger). The extra contribution involving the Yukawa couplings is positive definite and so it rises the bound. To obtain a numerical estimate of the latter these Yukawa couplings must be bounded by triviality arguments. That is, requiring the theory to remain perturbative up to some large scale Λ one can compute the maximum allowed values of the Yukawas at the electroweak scale. Inserting these values in Eq. (5) the tree-level upper bound (and the absolute one after inclusion of radiative corrections) is obtained.

We can study the bound (5) in some cases of interest.

i) **MSSM + singlets.** This is the simplest extension one can think of, possesing some appealing theoretical properties, and having been extensively studied in the literature[6–10]. We can choose the high scale Λ, up to which the theory should remain perturbative, to be Λ_{GUT} (the inclusion of gauge singlets does not change the good unification properties of the MSSM). The bound after the inclusion of radiative corrections is shown in Fig. 1b (we use the renormalization group method[7,10]; for alternative calculations see Ref. 11.). One can see that the bound is now weaker than that in the MSSM. In particular the absolute upper bound is 145 GeV.

ii) **General model perturbative up to Λ.** We can also address the problem of finding the absolute upper bound on m_h for supersymmetric models which remain perturbative below some fixed scale Λ. To maximize (5) we will need to saturate this scale, *i.e.* $\lambda^2(\Lambda)/4\pi \sim 1$, where λ is some generic coupling, and to slow the running of the Yukawas that appear in (5) by choosing the right Higgs representations (n_s, $t_{o,1}$). We can also add more doublets to saturate some gauge coupling and this helps in slowing the running of the Yukawas. The radiative corrections are included again using the RGE method and taking the scale of SUSY breaking of order 1 TeV. We performed this program[7] and obtained the absolute upper bound for any model perturbative up to Λ. Fig. 1c shows this bound for $\Lambda = 10^{16}$ GeV (also studied in Ref. 12.). The evolution of the bound with Λ can be seen in Fig. 1d where the MSSM case and the model with singlets are also plotted for comparison.

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Figure captions

Fig.1: Bounds on the light Higgs mass in different SUSY models: *a)* MSSM; *b)* MSSM + singlets; *c)* General model perturbative up to 10^{16} GeV; *d)* Models perturbative up to the scale Λ indicated.